

AGE ESTIMATES FOR GLOBULAR CLUSTERS IN NGC 1399

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ABSTRACT

We present high signal-to-noise Keck spectra for 10 globular clusters associated with the giant Fornax elliptical NGC 1399, and compare measured line indices with current stellar population models. Our data convincingly demonstrate, for the first time, that at least some of the clusters in a giant elliptical galaxy have super-solar abundance ratios, similar to the host galaxy. From $H\beta$ line-strengths the majority of clusters have ages of ~ 11 Gyrs (within 2σ), which is similar to the luminosity-weighted stellar age of NGC 1399. Two of the clusters (which also reveal enhanced abundance ratios) show significantly higher $H\beta$ values than the others. It remains unclear whether this is due to young (~ 2 Gyr) ages, or extremely old (> 15 Gyr) ages with a warm blue horizontal branch. However a conflict with current cosmological parameters is avoided if the young age is favored. Either alternative indicates a complicated age distribution among the metal-rich clusters and sets interesting constraints on their chemical enrichment at late epochs.

Subject headings: globular clusters: general – galaxies: individual (NGC 1399) – galaxies: star clusters.

1. INTRODUCTION

The metal-rich and metal-poor Globular Clusters (GCs) in our Galaxy, are thought to be both very old, i.e. ~ 13 Gyrs (e.g. Carretta *et al.* 2000) and enhanced in α elements, i.e. $[\alpha/\text{Fe}] \sim +0.3$ (Carney 1996). However the amount, and even the existence of a relative age difference between these two subpopulations is a matter of current debate.

Giant ellipticals also reveal two subpopulations of GCs (e.g. Larsen *et al.* 2001), with mean metallicities similar to those seen in spirals (Forbes, Brodie & Larsen 2001). Very little is currently known about the ages and abundance ratios of such GCs. The spectroscopic (Kissler-Patig *et al.* 1998; Cohen *et al.* 1998; Beasley *et al.* 2000) and recent photometric (Puzia *et al.* 1999; Kundu *et al.* 1999) studies suggest that both subpopulations are very old but the red (metal-rich) GCs could be up to as much as 5 Gyrs younger than the blue (metal-poor) ones. Abundance ratios for GCs in the giant ellipticals studied to date are consistent with Galactic GCs but individual errors are large. In the case of the merger remnant NGC 7252, Maraston *et al.* (2001) found GCs that had both young (~ 1 Gyr) ages and *solar* abundance ratios. Accurate measurements of individual GC ages and abundance ratios in elliptical galaxies will provide key constraints on the possible GC formation mechanisms (Ashman & Zepf 1992; Forbes, Brodie & Grillmair 1997).

In our previous spectroscopic study of NGC 1399 we obtained spectra of 18 GCs with the LRIS spectrograph on the Keck telescope (Kissler-Patig *et al.* 1998). These spectra indicated that the two subpopulations were old

and coeval within the errors (i.e. $\pm 0.5 \text{ \AA}$ in $H\beta$ Lick line index). Such errors were too large to clearly distinguish a relative age difference between the two subpopulations but they were generally consistent with old ages similar to those found in the Milky Way GC system. We also identified two metal-rich GCs with potentially super-solar abundance ratios.

Here we present higher S/N spectra (i.e. errors on $H\beta$ are about $\pm 0.25 \text{ \AA}$) for 10 GCs. These data are perhaps the highest quality spectra published for GCs beyond the Local Group and are comparable to the best spectra in the literature for M31 (Huchra *et al.* 1996) and Milky Way GCs (Trager *et al.* 2000). Errors in spectral line indices have a huge impact on our ability to estimate GC ages. For our previous dataset these errors translated into a relative age uncertainty of about ± 10 Gyrs for a 15 Gyr old GC. The data presented here have a corresponding error of ± 5 Gyrs. This allows us to better estimate the relative age of individual GCs and in particular identify GCs with young inferred ages in a giant elliptical galaxy for the first time. Here we confirm that the metal-poor GCs have $[\text{Fe}/\text{H}] \sim -1.5$ and are very old. We also identify two metal-rich GCs with super-solar abundance ratios (i.e. $[\alpha/\text{Fe}] > 0$) – such ratios are generally unexpected in late epoch mergers of spiral disks (Goudfrooij *et al.* 2001).

2. OBSERVATIONS AND DATA REDUCTION

Candidate GCs were selected from the list of Grillmair (1992) and observed on 1997 Sept. 30th and Oct. 1st using the LRIS spectrograph (Oke *et al.* 1995) on the Keck I telescope. The observational setup was the same

as used by Kissler-Patig *et al.* (1998) except integrations were longer at 13,200 sec. The 600 l/mm grating gave a resolution of 5.6 \AA .

Data reduction was carried out using the REDUX software package developed by A. Phillips. Using a series of scripts this package subtracts the bias, flatfields the data, removes the x - and y -distortions, and produces optimal sky subtracted 1-D spectra. Comparison lamp spectra of Hg, Ar, Ne and Kr were used for wavelength calibration. Spectra from the different nights were combined. Flux calibration was provided by the flux standard BD284211 observed on the first night. To correct the GCs onto the Lick/IDS system, we convolved our spectra with a wavelength-dependent Gaussian kernel and then applied small offsets obtained from observations of several Lick standard stars (see Beasley *et al.* in prep.).

Lick indices (Trager *et al.* 2000) were measured from our flux-calibrated spectra. Due to the variable nature of the wavelength ranges in multi-slit spectra, the same set of indices were not measured for all spectra. Uncertainties in the indices were derived from the photon noise in the unfluxed spectra. We have obtained spectra with $S/N = 30\text{--}45 \text{ \AA}^{-1}$, giving errors in the $H\beta$ index of $0.34\text{--}0.22 \text{ \AA}$.

Of the 17 usable spectra we confirm that 11 are *bona fide* GCs. We found objects #43 and #164 (IDs from Grillmair 1992) to be Galactic stars. Background galaxies (and their redshifts) are #40 ($z \sim 0.11$), #163 ($z \sim 0.07$), #167 ($z \sim 0.14$) and #169 ($z \sim 0.13$). Our sample of GCs have an average galactocentric distance of 20 kpc and cover the observed range of C-T₁ colors for the GC system (Ostrov, Geisler & Forte 1993). Velocities have been measured from the spectra via cross-correlation with high S/N spectra of two M31 GCs (158-213; $v_{\text{helio}} = -180 \text{ km/s}$ and 225-280; $v_{\text{helio}} = -164 \text{ km/s}$). The 11 GCs have a mean velocity of $1551 \pm 74 \text{ km/s}$ and velocity dispersion of $246 \pm 57 \text{ km/s}$. NGC 1399 itself has a velocity of $1447 \pm 12 \text{ km/s}$. One GC, #41 with velocity $1619 \pm 68 \text{ km/s}$, has been excluded from our line-strength analysis due to suspect sky-subtraction.

3. AGES AND ABUNDANCES

To investigate the properties of our GC sample, we primarily use the stellar population models of Maraston & Thomas (2000) which predict line-strength indices using the Lick/IDS-based fitting functions of Worthey (1994). It is important to check that we have adequately corrected the data onto the Lick system. To this end, we have compared index-index plots of our data with the models, and generally find good agreement. The strongest (and best measured) features in the GC spectra, which we use in this study, are the primarily metallicity-sensitive Mg_2 , $Mg b$ and $\langle Fe \rangle$ indices (the mean of the Fe5270 and Fe5335), and the more age-sensitive $H\beta$ and $H\gamma_A$ (the broader of the two $H\gamma$ indices defined by Worthey & Ottaviani 1997). Our line index measurements for the 10 GCs in NGC 1399 are listed in Table 1. We also include T₁ magnitudes (similar to Johnson R) and C-T₁ colors from Geisler, Forte & Dirsch (in prep.).

In Fig. 1 we plot the magnesium and iron indices of the GCs, and for the central line-strength of NGC 1399 itself (taken from Kuntschner 2000). At low metallicities, the GCs follow the models reasonably well. However, at

higher metallicities, the NGC 1399 GCs deviate significantly from the grids. The metal-rich GCs seemingly show an enhancement of magnesium with respect to iron, and an enhancement of $Mg b$ with respect to Mg_2 .

This behavior is also exhibited by NGC 1399 itself, which lies to the right of the population models. The fact that these magnesium lines do not vary in the same fashion does not indicate that we are unable to measure these indices. Rather, these indices (i.e. the bandpasses) have different contributions from elements other than magnesium (e.g. Tripicco & Bell 1995; Trager *et al.* 2000). Since the models of Maraston & Thomas (2000) use scaled-solar isochrones, we conclude that this offset arises because the metal-rich GCs in our sample have non-solar abundance ratios, i.e. $[Mg/Fe] > 0$. This result is consistent with high-resolution spectroscopy of bright giants in Galactic GCs, which typically exhibit $[\alpha/Fe] \sim +0.3$ (Carney 1996). Due to the small difference between solar and α -enhanced isochrones at low metallicities (e.g. Salaris & Weiss 1998) it is possible that the metal-poor GCs also possess super-solar abundance ratios.

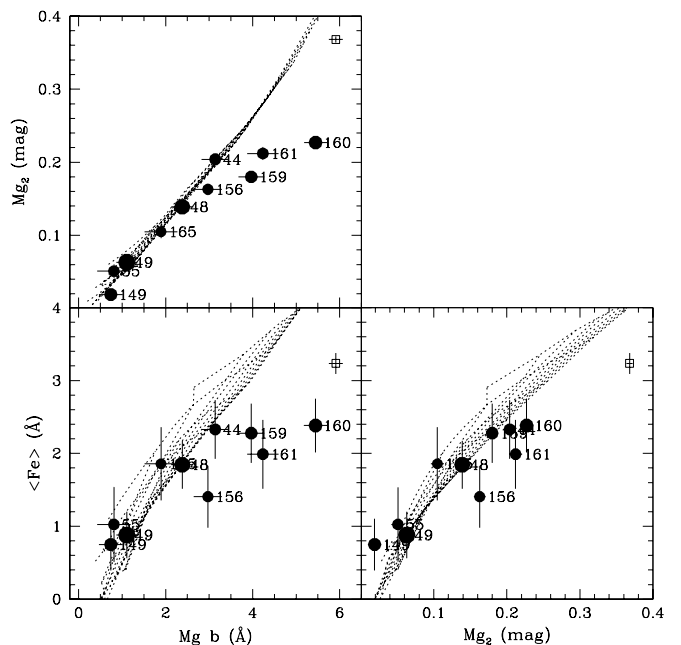


FIG. 1.— Comparison of primarily metallicity-sensitive Lick/IDS indices. Filled, numbered circles with error bars are the NGC 1399 GCs. Symbol size is roughly proportional to the S/N of the spectra. The open square indicates the position of NGC 1399 (Kuntschner 2000). Over-plotted are the stellar population models of Maraston & Thomas (2000) for ages between 1 and 15 Gyrs (left to right), and $-2.25 < [Fe/H] < +0.67$ (lower left to upper right).

The stellar population models can be used to disentangle age and metallicity, albeit in a model dependent way, and derive *relative* ages and metallicities for the NGC 1399 GCs. In particular we use the hydrogen Balmer lines which are strongly age sensitive combined with magnesium and iron which are largely metal sensitive.

In Fig. 2 we show our GC data compared to the stellar population models of Maraston & Thomas (2000) ex-

tended to younger ages (Maraston 2001, private comm.). To complement Mg_2 , our most robust measure of metallicity, we use $[MgFe]$ ($[Mg\ b \times \langle Fe \rangle]^{0.5}$), which minimizes the effects of the overabundance seen in $Mg\ b$, whilst increasing measurement accuracy (Gonzalez 1993). We have chosen to derive ages and metallicities for the GCs using the Maraston grids, since these are calibrated on Galactic GCs. In Table 1, we list the derived ages and metallicities of the GCs, obtained from the mean of the values predicted in the upper two panels of Fig. 2. Uncertainties are obtained by perturbing the line-strengths by their errors and re-deriving their ages and metallicities. We emphasize that these uncertainties represent the random measurement errors, and do not include possible systematic errors in the models themselves.

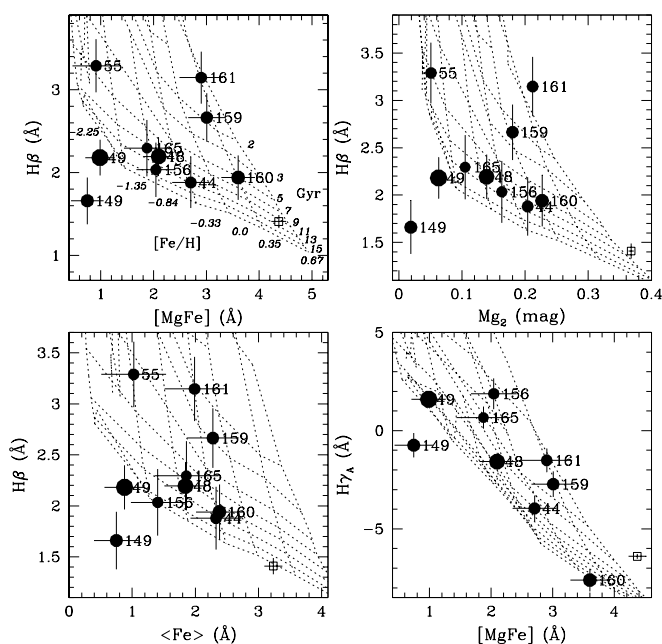


FIG. 2.— Index measurements of NGC 1399 GCs compared to the stellar population models of Maraston & Thomas (2000). The open square indicates the position of NGC 1399, from Kuntschner (2000). For the final ages and metallicities we use the upper two grids. *Top left:* $H\beta$ – $[MgFe]$ grid. *Top right:* $H\beta$ – Mg_2 grid. *Bottom left:* $H\beta$ – $\langle Fe \rangle$ grid. *Bottom right:* $H\gamma_A$ – $[MgFe]$ grid. The spectrum of GC #55 does not include $H\gamma_A$.

In Fig. 3 we show integrated spectra of three GCs associated with NGC 1399. As described below, two of the GCs (#161, #159) exhibit Balmer and metal line-strengths consistent with very young ages (notice in particular the strong $H\beta$ and Mg features in the spectrum of #161). Cluster #49 represents our highest S/N spectrum ($H\beta$ error is $\pm 0.22\ \text{\AA}$) and is an example of an old metal-poor GC.

The majority of the GCs are old (as found by Kissler-Patig *et al.* 1998) and are consistent with the 11 Gyr isochrone, within 2σ of their individual measurement errors. This age is consistent with the luminosity weighted age for the central stellar population of NGC 1399, i.e. 10 ± 2 Gyr using the line index measurement of Kuntschner

(2000). One metal-poor GC (#149) falls *below* the oldest model isochrones, possibly reflecting the uncertainties in modelling horizontal-branches in the models.

Interestingly, two of the GCs (#159 and #161) have very young inferred ages of ~ 2 Gyrs. Such young ages are consistent in all four model grids of Fig. 2, including $H\gamma_A$. Worthey (1994) models also indicate young ages. Significantly, the age estimates from $H\beta$ – $[MgFe]$ and $H\beta$ – $\langle Fe \rangle$ are both consistent indicating that the non-solar $[\alpha/Fe]$ ratios of the GCs are *not* responsible. It is important however to recognise that the population models are somewhat uncertain at very young ages, because they use fitting-functions derived only from old stars.

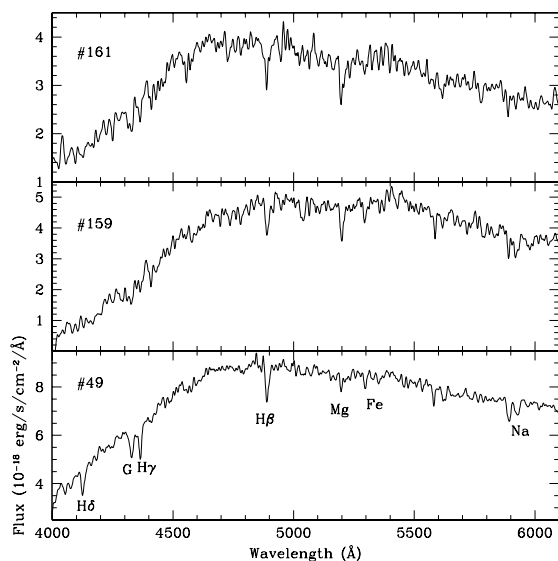


FIG. 3.— Keck spectra of three globular clusters around NGC 1399. The spectra have been convolved with a wavelength-dependent Gaussian kernel to match the Lick/IDS resolution (8–11 \AA). Clusters #159, 161 are inferred to be metal-rich and young whereas #49 is an example of a metal-poor old cluster.

Kissler-Patig *et al.* (1998) also identified two GCs (#83 and #102 from Grillmair 1992) with strong Balmer and metal lines, and potentially very young ages albeit with large errors. One possibility raised by these authors was that their enhanced Balmer lines were due to the presence of blue horizontal branches (BHBs).

de Freitas Pacheco & Barbuy (1995), Maraston & Thomas (2000) and Lee *et al.* (2000) have investigated the potential influence of a BHB on the $H\beta$ line index. According to Lee *et al.* a warm BHB can raise the $H\beta$ EW in metal-rich GCs by up to $0.75\ \text{\AA}$, without significantly affecting the metallicity, *if* those GCs are ~ 4 Gyrs older than Galactic ones. For metal-rich Galactic GCs, with estimated ages ~ 13 Gyrs, the increase in $H\beta$ from a BHB is minimal. Thus assuming that GCs #159 and #161 are truly metal-rich with $[Fe/H] \geq 0$, then they must be ≥ 4 Gyr older than typical Galactic GCs in order for BHBs to explain their $H\beta$ EW. If we accept current estimates for the oldest Galactic GCs to be 12.5 Gyrs, then 16.5 Gyr GCs would be incompatible with the current best estimates for the age of the Universe (Gnedin, Lahav & Rees

2001). We note that future far-UV photometry may help to distinguish between the presence of a BHB and a young age (Lee 2001, private comm.)

So although we can not conclusively choose between these two alternatives, both have interesting implications. If the BHB interpretation is correct, it would be the first detection of BHBs in metal-rich GCs of an elliptical galaxy since the initial discovery in two metal-rich Galactic GCs by Rich *et al.* (1997). It also implies that at least some GCs in NGC 1399 are systemically older than their Galactic counterparts by at least 4 Gyrs, and hence in conflict with the age of the Universe under certain cosmologies. The alternative is that these GCs, which are both metal-rich and have super-solar [Mg/Fe] abundance ratios, formed only ~ 2 Gyrs ago. Whether these GCs formed in an accreted satellite or *in situ* is not clear, but to attain the enhanced abundance ratios would require that they formed very soon after the first type II SNe. According to Thomas, Greggio & Bender (1999), a recent merger would require an extremely flat IMF to reproduce the observed α enhancement. However late epoch mergers of spiral disks, like the Milky Way, would *not* be expected to form α enhanced metal-rich GCs (Goudfrooij *et al.* 2001).

4. CONCLUDING REMARKS

From high S/N spectra and the stellar population models of Maraston & Thomas (2000) we find that the ma-

jority of globular clusters in NGC 1399 are old, similar to the luminosity-weighted age of NGC 1399 itself. At least two clusters have super-solar abundance ratios, again like the host galaxy. A super-solar abundance ratio for metal-rich stellar populations is a natural outcome from a fast, clumpy collapse but may also be produced by mergers if star formation has a sufficiently flat IMF (Thomas, Greggio & Bender 1999). Two metal-rich GCs are reported with unusually high H β line strengths. It remains unclear whether this is due to a young (~ 2 Gyr) age, or extremely old (> 15 Gyr) age with a blue horizontal branch. However a conflict with current cosmological parameters is avoided if the young age is favoured.

5. ACKNOWLEDGMENTS

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TABLE 1. CANDIDATE GLOBULAR CLUSTERS AROUND NGC 1399

| ID ^a | H γ (Å) | H β (Å) | Mg <i>b</i> (Å) | Mg ₂ (mag) | <Fe> (Å) | T ₁ (mag) | C-T ₁ (mag) | [Fe/H] ^b (dex) | Age ^b (Gyr) | V _{helio} (km/s) |
|-----------------|-------------------|------------------|--------------------|--------------------------|-------------|-------------------------|---------------------------|------------------------------|---------------------------------|------------------------------|
| 44 | -3.96±0.65 | 1.88±0.31 | 3.14±0.32 | 0.204±0.008 | 2.33±0.40 | 21.19±0.01 | 1.75±0.02 | -0.3±0.3 | 10 ⁺⁶ ₋₅ | 1127±41 |
| 48 | -1.57±0.45 | 2.19±0.24 | 2.38±0.25 | 0.139±0.006 | 1.85±0.33 | 20.58±0.01 | 1.43±0.01 | -0.8±0.2 | 10 ⁺⁴ ₋₄ | 1831±48 |
| 49 | 1.60±0.37 | 2.18±0.22 | 1.11±0.24 | 0.063±0.006 | 0.88±0.32 | 20.48±0.01 | 1.22±0.01 | -1.7±0.2 | ~ 15 | 1618±64 |
| 55 | ... | 3.29±0.32 | 0.81±0.39 | 0.051±0.009 | 1.03±0.51 | 20.87±0.01 | 1.14±0.01 | -1.9±0.3 | 7 ⁺³ ₋₃ | 1364±65 |
| 149 | -0.75±0.62 | 1.66±0.28 | 0.74±0.27 | 0.019±0.007 | 0.75±0.35 | 20.84±0.01 | 1.14±0.01 | -2.2±0.3 | ≥ 15 | 1361±107 |
| 156 | 1.88±0.78 | 2.03±0.33 | 2.97±0.32 | 0.163±0.008 | 1.41±0.42 | 21.12±0.01 | 1.50±0.02 | -0.7±0.4 | 11 ⁺⁷ ₋₇ | 1662±43 |
| 159 | -2.73±0.65 | 2.66±0.29 | 3.97±0.30 | 0.180±0.008 | 2.28±0.41 | 21.08±0.01 | 1.47±0.02 | 0.1±0.3 | 2.3 ⁺¹ ₋₁ | 1579±41 |
| 160 | -7.61±0.58 | 1.94±0.27 | 5.45±0.27 | 0.227±0.007 | 2.38±0.37 | 20.75±0.01 | 1.72±0.01 | 0.2±0.3 | 7 ⁺⁶ ₋₄ | 1378±32 |
| 161 | -1.51±0.59 | 3.15±0.31 | 4.23±0.36 | 0.212±0.009 | 1.99±0.47 | 20.89±0.01 | 1.45±0.01 | 0.3±0.3 | 1.6 ⁺¹ ₋₁ | 1506±45 |
| 165 | 0.67±0.56 | 2.30±0.34 | 1.89±0.38 | 0.105±0.009 | 1.86±0.50 | 20.82±0.01 | 1.43±0.01 | -1.0±0.3 | 11 ⁺⁷ ₋₅ | 2020±38 |

^aglobular cluster ID number from Grillmair (1992).^bmetallicity and age are derived using the single stellar population models of Maraston & Thomas (2000).